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AIRSCREW-ENGINE COMBINATIONS AND THEIR EFFECT ON THE TAKE-OFF

Recently "Flight" Published the Views of Well-known Designers on the Advantages of Variable-pitch Airscrews : The Author of this Article, who is Chief Designer of the Handley-Page Company, Deals with the Subject Quantitatively

By G. V. LACHMANN, Dr.-Ing., A.F.R.Ae.S.

THE following investigation is the outcome of an enquiry from the Editor of this paper concerning my views on variable pitch airscrews *versus* 2-speed gear and overboosting. A purely qualitative reply to this question is fairly simple and obvious. However, from a designer's viewpoint, a general statement is not entirely satisfactory and a quantitatively differentiated answer is required. To know which technical solution is sufficient is in practice often more important than a general conception of the method which gives the optimum result.

Taking the case of variable pitch airscrews, for example, the price and extra weight of these airscrews are still of such an order as to necessitate in certain cases a more critical investigation into the actual magnitude of the advantages gained. In the case of military aircraft, it may well happen that a machine with low power loading at full load may, even when fitted with a fixed pitch airscrew (the blades of which may stall during the initial part of the unstick run), clear the obstacle quite easily. In such a case the advantage gained by the use of a variable pitch airscrew may be unimportant considering the increase in price and weight and the added complication of another control in a cockpit already bristling with controls for mixture, air intake, two-speed blower, brakes, and flaps, in addition to the conventional air controls. Even when the specification calls for a special overload case which could not be met satisfactorily by a fixed pitch airscrew, the designer is inclined to ask whether simple overboosting would not give a satisfactory take-off, although perhaps with a lesser margin than a variable pitch airscrew but at least in a cheaper and simpler way.

With these considerations in mind, I have tried to find a more quantitative answer to the problem of the most suitable engine-airscrew combination and have confined myself to the influence on take-off only, as this is the outstanding problem, and further, I have tried to give an answer which is not too general and academic. As far as variable pitch airscrews or 2-speed gears are concerned, I do not refer to any particular design, but presume that the requirements can be mechanically satisfied. This may, in certain cases, necessitate the use of a variable pitch airscrew of infinite blade settings, which is obviously the ideal type.

The Interaction of Airscrew and Engine Torque

From the fundamental equations for torque and thrust of an airscrew follows

$$T = \frac{Q}{D}\frac{K_T}{K_Q}$$

i.e., the thrust of an airscrew depends on the ratio of the non-dimensional expressions K_T and K_Q and on torque and airscrew diameter.

Airscrew Characteristics and Static Thrust

If the diameter D be fixed by considerations of optimum efficiency, ground clearance, etc., the take-off length is determined by the values of $Q \times \frac{K_T}{K_Q}$ obtained during the take-off period, as obviously the greatest thrust will give quickest acceleration from standstill to take-off speed and the shortest climb over the obstacle. It should be noted that it is the interaction between torque and airscrew characteristics expressed by this simple law which determines the thrust and not in the first place, as is rather a popular misconception, the number of r.p.m. obtained. Unfortunately

this conventional method breaks down for calculating the static thrust of high pitch airscrews because the available data based on wind tunnel tests are either incomplete or entirely unreliable.

In this country R & M.829 has formed a time-honoured source of information in regard to airscrew performance calculations. These airscrews were tested in a closed tunnel which makes the results unsuitable for static thrust calculations, at least at P/D ratios $> .7$. Apart from the fact that an airscrew always produces a certain amount of flow in a tunnel, which makes it impossible to obtain a true zero speed reading, the inflow of a stationary airscrew in free air is quite different from the conditions in a closed tunnel where the walls smooth out the flow. In free air, the air flows in from all sides, forming a kind of vortex ring (see Fig. 1). This difference in inflow apparently

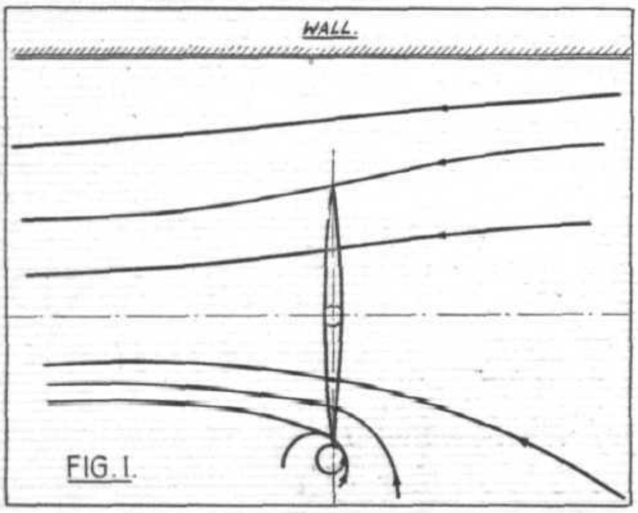


FIG. 1.

results in a premature stall of the tips and accounts partly for the difference between full scale static thrust and thrust predicted from wind tunnel results.

American and recent N.P.L. Tests were done in open jet tunnels, where the inflow is probably more in accordance with full scale; however, the static thrust has not been measured due to the difficulty in obtaining a zero speed reading, and one has to rely on extrapolation. Besides, all wind tunnel tests, whether done in a closed or open jet tunnel, fail to bring out the effect of tip speed, which, according to American full scale tests, has an important bearing on the static thrust.

The only reliable full-scale data at the moment are tests by the Hamilton Standard Propeller Company published in S.A.E. Journal for August and September, 1934. (Aircraft Propeller Development summarised by Frank W. Caldwell, Research Engineer of the Hamilton Standard Propeller Company.) The Americans have adopted the so-called "static thrust efficiency" as an expression of the momentum horsepower over the actual horsepower. It would appear that this way of expressing static thrust is based on certain deductions which, according to my knowledge, were first published by Bendemann in 1918.* From the momentum theory follows the so-called axial efficiency of an airscrew:

$$\eta_a = \frac{2}{1 + \sqrt{1 + k_s}} \quad \ldots \quad (1)$$

where $$k_s = \frac{T_i}{\rho/2 \; A_e v^2} \text{ (airscrew disc loading)}. \quad \ldots \quad (2)$$

T_i = Ideal maximum thrust.
A_e = Airscrew disc area.
v = Airspeed.

Considering that:

$$\eta_a = \frac{T_i \cdot v}{P_m} \quad \ldots \quad (3)$$

The following equation is obtained by combining (1), (2) and (3):

$$T_i^3 + 2\rho A_e P_m T_i v - 2\rho A_e P_m^2 = 0 \quad \ldots \quad (4)$$

The ideal static thrust T_o follows by putting $v = 0$.

$$T_{io} = (2P_m^2 \rho A_e)^{\frac{1}{3}} = 1.16 \, \rho^{\frac{1}{3}} (P_m \, . \, D)^{\frac{2}{3}} \quad \ldots \quad (5)$$

The ratio between actually obtained static thrust and the ideal maximum thrust is therefore:

$$J_o = \frac{T}{(2P_m^2 A_e \rho)^{\frac{1}{3}}} = \frac{.25 K_T}{K_Q^{\frac{2}{3}}} \quad \ldots \quad (6)$$

The thrust can therefore be expressed as a function of horsepower, density and a ratio J_o which has to be determined empirically.

$$T_o = J_o \, . \, \rho^{\frac{1}{3}} \, . \, 1.16 \, . \, (D \, . \, P)^{\frac{2}{3}} \quad \ldots \quad (7)$$

Instead of Bendemann's ratio, J_o the Americans are using a static thrust efficiency $\eta_s = J_o^{1.5}$ and the static thrust is found from:

$$T_o = \rho^{\frac{1}{3}} \, . \, 1.16 \, . \, 550^{\frac{2}{3}} (D \, . \, P \, . \, \eta_s)^{\frac{2}{3}} = 10.4 \, (D \, . \, P \, . \, \eta_s)^{\frac{2}{3}} \quad \ldots \quad (8)$$

Curves for η_s representative of aluminium alloy propellers of current type are shown in Fig. 2. This diagram clearly indicates the effect of tip speed and the very pronounced effect of blade angle on static thrust. It also reveals very clearly the outstanding improvement of static thrust obtainable by the use of variable pitch airscrews on fast aircraft where a high P/D ratio is required for top speed.

Additional information is badly required in regard to the influence of blade width and blade section at the tips. From extrapolated wind tunnel test results it would appear that higher static thrust is obtained with wider blades. Diagram 3 contains a comparison of η_s for model airscrews from R & M.829 and full scale airscrews of the same P/D ratio running at their actual tip speed. These curves show a marked divergence in static thrust, especially for the higher pitch ratios, and indicate that the model tests become entirely unreliable and misleading. This lack of trustworthy data makes an investigation on purely

*Bendemann, Wirkungsgrad u. Gütegrad von Luftschrauben. Z.F.M. Bd.9 (1918).

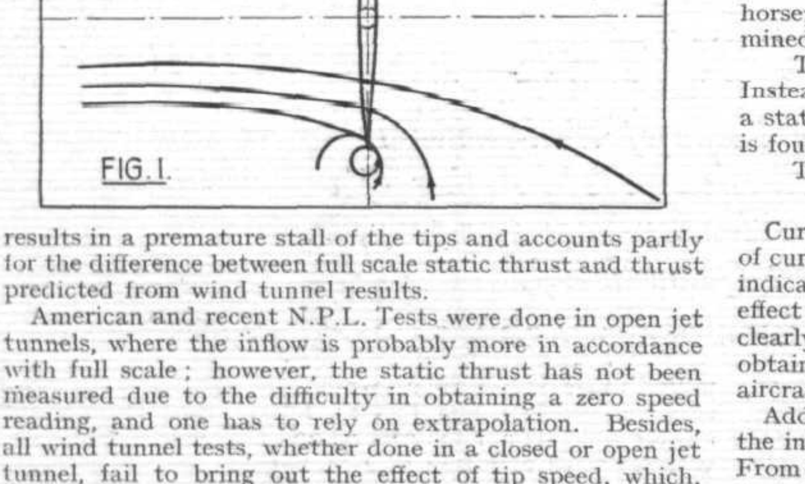


FIG. 2.

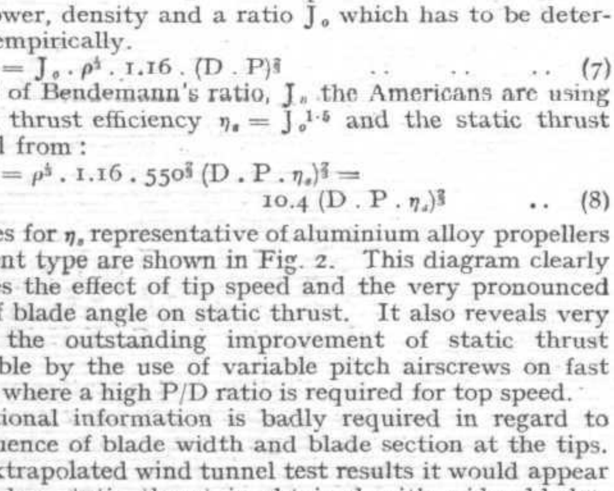


FIG. 3.

analytical lines rather difficult. However, it seems to be fairly reasonable to base an investigation on the American full scale results for static thrust and to assume that once a certain critical speed has been exceeded the blades unstall. To determine this critical speed is, of course, somewhat arbitrary.

In the course of the following investigation, model K_T curves have been used up to that point of V/nD where the peak in the K_T curve occurs, and it was assumed that the thrust then falls off towards the static thrust value obtained from the American full-scale tests following a parabolic law.

In certain cases, for example, for the combination of overboosted engine and fixed pitch or variable pitch airscrew, it appears that there is a fairly wide region of V/nD within which the blades may unstall dependent on various circumstances. Therefore, the calculations have been based on two limiting thrust curves forming the most optimistic and most pessimistic boundaries of a region within which the actual thrust curve will lie.

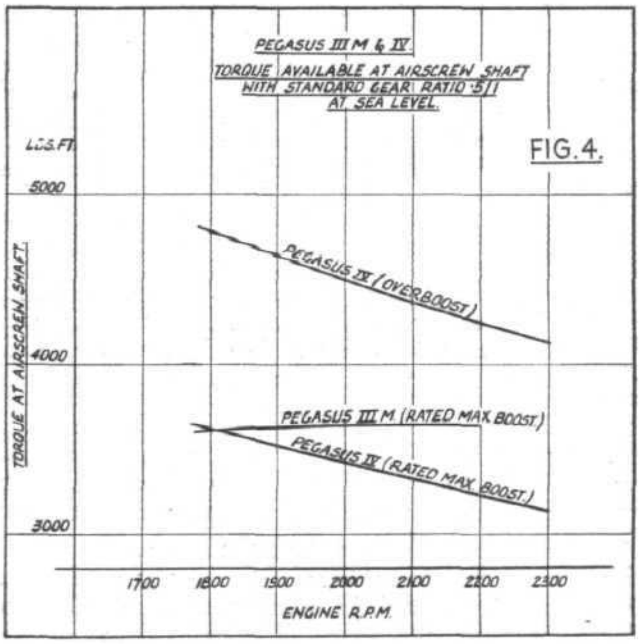


FIG. 4.

Engine Torque Characteristics

Having dealt with the airscrew, we now turn to the engine side. Diagram 4 contains torque curves for the two basic types now in use, the moderately supercharged engine and the fully supercharged engine, or the two-speed blower engine, respectively. Curves A and B refer to the Bristol Pegasus III and IV engines as typical British representatives. The rated maximum boost pressure is + 2 lb./sq. inch for the III and + 2½ lb./sq. inch for the IV. Water-cooled engines give similar characteristics. The divergent character of the torque curves should be noted, *i.e.*, the higher torque of the fully supercharged engine up to 1,800 r.p.m. At higher r.p.m. the moderately supercharged engine develops a higher torque.

Means for Improving Take-off Thrust

Such means can be sub-divided into two classes: (*a*) means which in the first place increase the torque supplied to the airscrew shaft, (*b*) means which in the first place prevent the stalling of the blades of the airscrew.

Under the first heading comes the practice of ground boosting which has lately become very popular in this country. It is well-known that the maximum boost pressure depends decisively on the octane figure of the fuel. With 87 octane fuel the usual values for the boost pressure are 4 to 6 lb./sq. inch. One may expect this figure to go up to 8 lb./sq. inch when Iso octane fuel comes into use. A torque curve (*c*) based on this boost pressure is shown in Diagram 4. In the following this method of increasing ground boost to 8 lb./sq. inch will be called "overboosting."

The two-speed gear comes into the same category, but to my knowledge no such device has ever been produced. There are indications that its design has been considered by engine makers, and I propose to treat it quite academically in the following as a possible means for increasing the torque without discussing the mechanical problems connected with its production and operation.

The variable pitch airscrew, as the only existing means of the second category, has begun to enjoy a well-deserved and increasing popularity. Anticipating some results of the following investigation, I should like to state here that the variable pitch airscrew is essentially an asset for fast aircraft and, as has been proved by others before, it is of little use to relatively slow machines.

(*To be continued.*)

AN AUXILIARY AEROFOIL FLAP

IN most of the cases where flaps are employed to increase the maximum lift of a wing, they are so constructed as to retract into or become a part of the main wing when in their low-drag attitude. A less common type consists of an auxiliary aerofoil which remains external to the main wing at all times. This latter type has been used on certain Junkers aeroplanes in Germany and tests have been made in the United States on a somewhat similar installation known as the Wragg compound wing.

Some time ago the American National Advisory Committee for Aeronautics carried out tests in the 7ft. by 10ft. open-jet tunnel on an auxiliary aerofoil of symmetrical cross-section, mounted in several positions near the trailing edge of the main wing. The auxiliary aerofoil had a chord 15 per cent. of the chord of the main wing, and its hinge line was set back 20 per cent. of the flap chord. It was found that the optimum location of the hinge line was found to be quite critical. Best results were obtained with the hinge line of the flap located 1¼ per cent. of the main wing chord behind the trailing edge and 2½ per cent. below the chord. With this location the leading edge of the flap touches the trailing edge of the main wing when the flap makes an angle of 45 degrees with the main wing chord. (The main wing was of Clark Y section.) When the flap is in the minimum drag position there is a gap between its top surface and the trailing edge of the main wing.

With the flap down 45 degrees and its hinge located as indicated above, the maximum lift coefficient was found to be 1.810 based on the total wing area (*i.e.* wing area plus flap area) and 2.080 based on the area of the main wing. This represents an increase of 45 per cent. over that obtained with the plain wing. The minimum drag coefficient was found to be decreased to 0.0146 at −5 degrees flap deflection. The coefficients, it should be noted, are twice the British "absolute" coefficients.

Lateral stability of the combination was measured by determining the initial angle at which autorotation was self-starting. It was found that there was no serious adverse change in lateral stability. Full data are published in N.A.C.A. Technical Note No. 524.

THE "CYCLOGIRO"

A CYCLOGIRO rotor having a span and diameter of 8ft. was tested in the American N.A.C.A. 20-foot wind tunnel. The tests showed that the cyclogiro would be able to ascend vertically, fly horizontally, and glide without power. The power required for normal flight would, however, be excessive. A comparison of calculated and experimental results showed that the analytical expressions used gave the correct variation of the power required with the rotor forces, but that the values calculated for zero rotor forces were in error.—(*N.A.C.A. Technical Note No.* 528.)

MAGNESIUM ALLOYS in AIRCRAFT CONSTRUCTION

Considerable progress has been made in the use of Elektron for aircraft and aero engine construction: The following account records some of the achievements.

THE application of Elektron in cast form for aero engines, landing wheels, and numerous other components of modern aircraft is too widely known to need recapitulation, the advantages of this strong and light metal having been recognised for years, and pioneer firms of light metal founders have, to a constantly increasing extent, supplied a very high-grade product to the aircraft and aircraft engine industries. The achievements of Sterling Metals, of Coventry, in handling a comparatively new metal, overcoming its peculiar difficulties, and in making Elektron castings, almost daily becoming more complicated and required to meet more and more searching specifications, are probably without parallel in founding as applied to light metals. The advances made in the production and applications of wrought Elektron are not, however, so widely known, and it is proposed, therefore, in this article to draw attention to this sphere.

What are commonly called wrought products in Elektron or in other materials are those produced by plastic deformation, with or without applied heat, as distinct from those formed by some casting process. The processes yielding wrought products, therefore, are extrusion, rolling, drawing, forging and stamping. All these operations are carried out with Elektron materials by James Booth & Co. (1915), Ltd., who are the sole manufacturers of wrought Elektron in this country, under licences held by that firm for the past five years for the use of all the relevant patents of the inventors. Elektron now has important application on aircraft in all these wrought forms.

Unstressed Parts First

It was quite natural, and, in fact, essential from a technical point of view, that wrought Elektron should enter the aircraft industry by way of applications which are unstressed or only lightly stressed. Indeed, its sponsors have been insistent that it did so enter, for the use of this metal postulated much that was new in manufacturing and fabricating, and since it was far more important to achieve a single successful application rather than many of uncertain value, the policy adopted was necessarily a cautious one. Consequently, Elektron was first put forward and accepted by constructors in the form of sheet and strip, for making cowlings and fairings. Its qualifications for such work lie in the fact that it is 40 per cent. lighter and about twice as strong as aluminium, and for these advantages in weight reduction and strength, considerable cost in its fabrication was deemed justified.

These advantages cost something also in effort, for Elektron differs from the usual constructional materials in that it must be worked warm, if any but the smallest deformations have to be effected, and while this fact deterred the timorous constructor, the bolder workers went forward to overcome the difficulties; indeed, the successful working of Elektron lies essentially in taking the decision to depart from usual metal practice, and work it hot. Once this decision is taken the only real hindrance to progress is removed and rapid advancement is sure.

It can be said that of all those constructors who have taken the decision boldly, none has later abandoned the use of Elektron.

The major use of wrought Elektron in aircraft construction comprises the alloy AM 503, in the form of sheet and strip. This alloy, easily welded and workable at temperatures between 270° and 320° C., is particularly suitable for making cowlings and fairings.

Welding AM 503 by the oxy-acetylene process is quite easy, giving strong and durable results. Perfection in the welding operation, given the right fluxes, is really a matter of manipulative skill, since a craftsman skilled in welding alumunium can become quite expert with Elektron in a few days. In the *as welded condition*, tests taken at right angles to the line of weld show 50 to 60 per cent. of the strength of the unwelded sheet, but when these welds are hammered this proportion becomes 80 to 90 per cent., such a satisfactory result being secured with certainty after hammering of the welded metal. Once welded, the sheet can be beaten and bent with all the facility of the unwelded material. The British Oxygen Co. not only manufactures and markets standard fluxes and welding rods, but undertakes to demonstrate the oxy-acetylene welding process to users of Elektron. Electric spot and seam welding are also possible on Elektron, and have been successful experimentally. The application of these processes to full-scale manufacture is now steadily developing.

Not all joints, however, lend themselves to welding, and for those which must be riveted rivets of M.G.5 alloy are available. The idea, now somewhat prevalent, that hot riveting is necessary in Elektron structures is fallacious, and M.G.5, an alloy of aluminium with 5 per cent. magnesium, has been devised as being suitable for cold heading, but does not introduce any corrosion problem if used in conjunction with Elektron. Magnesium in the rivet alloy is added partly in order to give to the rivets an electro-chemical potential of the same order as Elektron itself, and therefore M.G.5 or M.G.7 may be used with the utmost confidence in close conjunction with Elektron.

Elektron Tanks

Elektron is a very suitable material for fuel tanks, being very extensively utilised for that purpose on the Continent. In this country the application has not yet been advanced very largely, though experimental tanks have been made. Their wide practical employment has probably not been achieved up to the present because at the time the first experiments were conducted, the working and welding of Elektron had not advanced to anything like its present state, and the early tanks suffered from manufacturing, rather than functional defects.

Another thing which has delayed this application is that, with doped fuels, there is a slight attack between the fuel and the metal, if water is present. While this fact has undoubtedly delayed British development, it has been completely and satisfactorily overcome on the Continent, where it was realised that if water was present in the fuel tank (and it always is in practice) the water is confined by gravity to the sump or pockets, and therefore surmounting this difficulty is mainly a matter of design of the tank. To counteract any attack that might occur, owing to distribution of the water from turbulence caused by the movements of the aircraft, a protective capsule has been developed, and is included in the tank, containing a reagent which inhibits corrosive attack, without in the least affecting the fuel.

While the above disadvantage has been cited in the consideration of Elektron for fuel tanks, it cannot exist as regards oil tanks, and yet despite the very great weight-saving which is effected by using Elektron in this application, no real development has yet taken place in installing Elektron oil tanks in British aircraft, although both for fuel and oil tanks it is satisfactory to note that a number

of constructors are now giving very close consideration to this application.

Perhaps rapid progress in the matter will follow naturally upon the success which has been achieved with Elektron cowlings, fairings, panelling, bulkhead frames, etc., etc., since the latter uses have established the technique of fabricating the material.

Fabricating Elektron, even while taking into account fully the hot technique or warming procedure which has to be followed, is really little more costly than the production of metal work by the old methods, because constructors have developed quite ingenious methods of maintaining a suitable temperature in the metal and working tools. For example, it is the boast of one fabricator that he can make a set of cowlings in Elektron as cheaply as in aluminium—excluding the initial cost of the metal—which is one way of saying that this worker's hot technique costs him no more than the cold fabricating processes hitherto utilised with other materials.

The discussion of fabricated products in Elektron must not be left without mentioning drawn sections which are available in great variety for stiffening skin structures. In general, such drawn sections start where practicable extrusions leave off, namely at about $\frac{1}{16}$in. thick, and they are produced down to such a light thickness as 22 gauge, or in certain cases even thinner. Sections having a weight as low as .05lb. per foot run, with from 15 to 17 tons per square inch tensile strength, can be supplied. When welded or riveted to sheet, these sections lend really astonishing stiffness to the construction. Here the metal producers can be of the utmost assistance in demonstrating the best technical methods.

Extruded Rods, Bars, Sections and Tubes

These are produced from the stronger alloy AZM by extrusion, and such products can be relied upon to have a 0.1 per cent. proof stress of 8 to 10 tons, a maximum stress of 18 to 20 tons per square inch, and elongation ranging from 17 down to 10 per cent. Extruded products of Elektron AZM now have extensive application for machined parts of engines and engine mountings. AZM tubes are extensively employed for interior furnishings of aircraft, including hand-railing, chairs, luggage racks, etc. Rumbold and Co., Ltd., of Kilburn, N.W.6, have specialised in this form of construction and produce most rigid and comfortable chairs of very light weight.

Forgings and Stampings

Forgings and stampings in Elektron are a rapidly increasing application in the aircraft industry, confidence in this use owing a great deal to the very successful airscrews made in the metal. Elektron airscrew blades form the most interesting and important application in the forgings sphere, despite the fact that up to the present the airscrew output, measured in tonnage, is very much less than the aggregate of the small forgings of Elektron now in common use.

For over three years some 30 airscrews, having blades forged by James Booth and Co. (1915), Ltd., and blades machined and mounted by the Bristol Aeroplane Co., have been undergoing flight trials in service machines all over the world. They have been used with engines of various types, developing 500 to 600 h.p., at airscrew speeds of 1,000 to 1,100 r.p.m.

Although there has been a very great deal of controversy on the point, there is a fairly general consensus of opinion that ultimately the variable pitch airscrew will come into general use in this country.

Airscrew Blade Forgings

Elektron is considered a promising material for airscrew blades because of the mechanical properties comprised in the latest forgings, which have a 0.1 per cent. proof stress of not less than 10 tons per square inch in any part, a maximum stress ranging from 17 to 20 tons per square inch, elongation often as high as 15 per cent., and in no case less than 8 per cent., and a transverse strength in the root of the blade of 12 to 15 tons per square inch. These figures, considered with the fatigue limit (Wöhler) of plus or minus 7.5 to plus or minus 8.5 tons per square inch, at 10 million cycles, and the specific gravity of 1.82, seem to constitute a considerable claim for Elektron.

The properties given above are available also, and even exceeded, in smaller forgings now used for miscellaneous engine parts. Forgings of this type are being employed in the operating parts of retractable undercarriage and wing-flap gear, so that there is no doubt of great further extension on similar lines.

The increased confidence now becoming general, and the rapidly increasing use of wrought Elektron in the aircraft industry, result not only from the vigorous and costly development work performed with this material by certain constructors, but also from the important improvements in the properties of the Elektron alloys themselves. Notably, the latter is true in regard to mechanical properties and resistance to corrosion.

Improvements have been effected partly by metallurgical refinement and new alloying processes, and also by discoveries of valuable protective finishes. Illustrating the latter may be mentioned that throughout the trials of Elektron airscrews in service machines there has been no mention of any trouble due to corrosion or to excessive erosion of the leading edge. The blades are protected by the chromating process developed at the R.A.E. with a finish of suitable varnish or lacquer.

Erosion of the leading edge does not, it is claimed, occur to any greater extent with Elektron than on any other metal blade.

A.M.503 ALLOY FOR BARS AND SHEETS

Mechanical and Physical Properties and Chemical Analysis.

Proof Stress (tons per sq. in.), 0.1%	7 to 9
Maximum Stress (tons per sq. in.)	12 to 17
Elongation on 2" (per cent.)	10 to 3
Reduction of Area (per cent.)	30 to 25
Compression Strength (tons per sq. in.) ..	18 to 22
Shear Strength (tons per sq. in.)	8
Fatigue Range (tons per sq. in.)	± 6
Izod Impact Test, Energy absorbed (ft. lbs.)	3 to 5
Brinell Hardness	40 to 50
Modulus of Elasticity (in lbs. per sq. in.) ..	6.0×10^6
Specific Gravity	1.81 to 1.83
Weight per cubic inch (in lbs.)	0.0654
Melting Point (degrees Centigrade)	645
Coeff. of Thermal Conductivity (c.g.s. units at 18° C.)	0.32
Coeff. of Thermal Expansion (per ° C.) Average 20° to 100° ..	0.0000240
20° to 150° ..	0.0000247
20° to 200° ..	0.0000254
Specific Heat (at 20° C.)	0.24
Electrical Conductivity (Copper 100) ..	25 to 32
Colour Symbol..	Yellow Red

The mechanical properties given above are average test values obtained from 1" dia. Extruded Bars machined to 0".564 dia. × 2" gauge length.

The figures given represent Extruded Bars up to 2" dia. Above this dia. the properties are somewhat lower.

Sheets have similar properties to the above.

	D.T.D. Specn.	*Supplied as*	*Aluminium Max.*	*Zinc. Max.*	*Manganese Max.*	*Magnesium Approx*	*Impurities Max.*
A.M.503	140 142 118	Sand Castings ... Extrusions Sheets	0.20	0.20	2.50	96	0.50

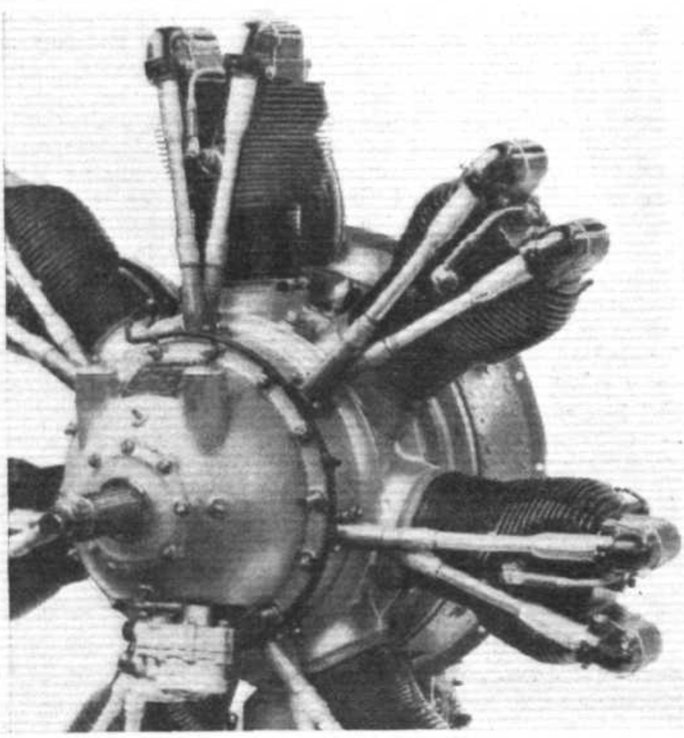
A NEW SIDDELEY ENGINE

TO the already long range of Siddeley engines has just been added the "Cheetah IX," a seven-cylinder radial rated at 310 b.h.p. at 2,100 r.p.m. at 6,000 ft.

The new engine resembles generally the earlier "Cheetah VI," but is designed to run on the new 87 Octane fuel, with consequent gain in performance. Structurally the "Cheetah IX" follows usual Siddeley practice. The characteristics of the engine are fully shown in the table of data and the power curves.

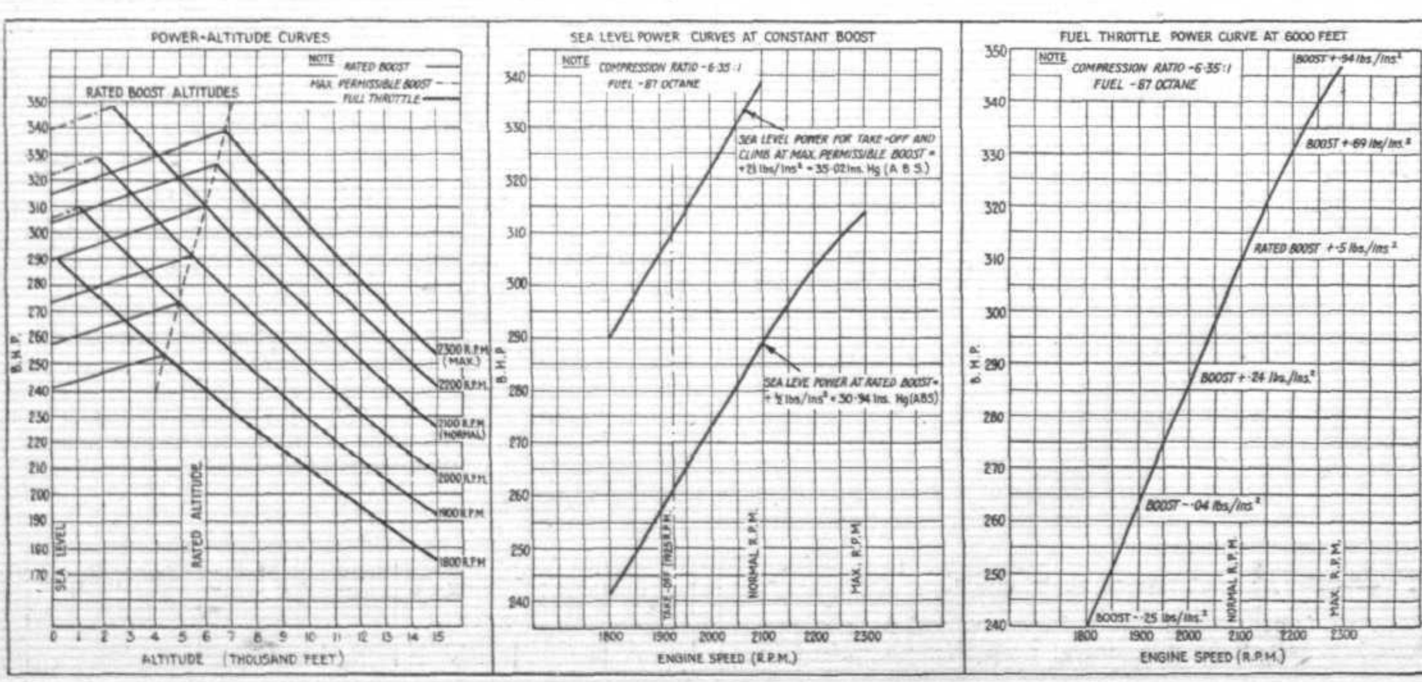
It will be noted that considerably more power is available than that of the older model. For instance, the power at sea level and maximum speed is 314 b.h.p., while the maximum power at the maximum engine speed of 2,300 r.p.m. and at 6,800 ft. has gone up to 339 b.h.p., a very substantial gain on the earlier models.

The military version of the Avro 652, now known as the Avro "Anson," is being equipped with the Siddeley "Cheetah IX" engines, and with them the maximum speed should be even better than that of the civil machine, which was little short of 200 m.p.h.



ARMSTRONG SIDDELEY CHEETAH MK. IX ENGINE.

SPECIFICATION.	
Type	Air-cooled Radial.
Direction of rotation	Left-hand tractor looking forward.
Induction system	Geared fan. Ratio 6 to 1
Drive to airscrew	Direct.
No. of cylinders	7.
Bore	5.25 in. (*133.3 mm*)
Stroke	5.5 in. (*139.7 mm*)
Swept volume	834 cu. in. (*13.65 l*)
Compression ratio	6.35 to 1.
ENGINE SPEED.	
Normal	2,100 r.p.m.
Maximum	2,300 r.p.m.
Take-off	1,925 r.p.m.
ENGINE POWER.	
At Altitude.	
(a) Rated power at normal speed	310 b.h.p. at 6,000 ft.
(b) Max. power at max. speed	339 b.h.p. at 6,800 ft.
At Maximum Permissible Boost (+2½ lb./sq. in.).	
(a) Power at take-off speed	310 b.h.p.
(b) Power at normal speed	339 b.h.p.
At Sea Level and Rated Boost (+½ lb./sq. in.).	
(a) Power at normal speed	289 b.h.p.
(b) Power at maximum speed	314 b.h.p.
Oil consumption	4–7 pt./hr. (2.27–3.97 *l/h*)
Fuel consumption	0.6 pt./b.h.p./hr.
Fuel	To specification D.T.D.230 Octane value not less than 87.
Tachometer drive (Elliott)	½ engine speed.
Carburetter	Claudel Hobson A.V.70.D.
Magnetos (2 fitted, fixed ignition)	B.T.H.
Sparking plugs (2 fitted per cylinder)	K.L.G. V.7.
WEIGHT.	
Bare and dry	641 lb. (*291 kg*)



Power-altitude, sea level and full-throttle power curves of the Armstrong-Siddeley "Cheetah IX." This engine is a moderately supercharged seven-cylinder radial air-cooled, with direct drive. It is rated at 310 b.h.p. at 2,100 r.p.m. at 6,000 ft.

TECHNICAL LITERATURE

SUMMARIES OF AERONAUTICAL RESEARCH COMMITTEE REPORTS

REPORTS published by His Majesty's Stationery Office, London, which may be purchased directly from H.M. Stationery Office at the following addresses: Adastral House, Kingsway, W.C.2; 120, George Street, Edinburgh; York Street, Manchester 1; St. Andrew's Crescent, Cardiff; 15, Donegall Square West, Belfast; or through any ordinary bookseller.

ON THE CALCULATION OF STRESSES IN BRACED FRAMEWORKS. V. THE GENERAL SOLUTION FOR A CYLINDRICAL TUBE OF REGULAR POLYGONAL CROSS SECTION. By R. V. Southwell, F.R.S., and J. B. B. Owen, B.Sc. R. & M., No. 1573. (87 pages and 2 diagrams.) June 19, 1933. Price 4s. net.

Part I contains a résumé of the underlying theory, together with some new relations which are needed for the purpose of the present discussion. Equations and formulæ which were established in the original paper are quoted without proof.

Two particular problems are discussed as illustrative examples relating to a three-bay hexagonal framework of which the dimensions and elastic properties conform with those of a model made and tested by Professor A. J. S. Pippard and Mr. J. F. Baker.[1] In Part II of the paper all bulkheads are assumed to have radial bracing of the same stiffness (Case 4 of the experimental investigation); the numerical calculations have been made by Mr. J. B. B. Owen, a research student working in the Engineering Laboratory at Oxford. In Part III Mr. Owen discusses the modifications in method which are required when (as in Case 1 of the experimental investigation) only the terminal bulkheads are braced.

In Part IV, Mr. Owen discusses the validity of a remark made in a footnote to the original paper, that "it is not essential to the analysis that the bulkheads shall in fact be braced with radial wires in the manner shown: the results of this paper will hold provided that the behaviour of the polygonal ring, when loaded by radial forces, is such as can be represented by equivalent radial bracing." He finds that it is not possible to replace a stiff unbraced ring by an exactly equivalent system comprising a pin-jointed ring and radial bracing; but on the other hand, that if the basic equations (of equilibrium) are modified to take account of the new conditions, no fundamental difference is made to the subsequent analysis.

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1 R. & M. 948. "An experimental investigation into the properties of certain framed structures having redundant bracing members." The dimensions, etc., are given in the Appendix to this paper.

CONSUMPTION MEASUREMENTS IN FLIGHT WITH VARIABLE IGNITION. By J. L. Hutchinson, B.A., and E. Finn, B.Sc. Communicated by the Director of Scientific Research, Air Ministry. R. & M., No. 1612. (8 pages and 15 diagrams.) December, 1933. Price 9d. net.

An investigation into the effect of ignition timing upon the range of aircraft with air-cooled engines has been made in continuation of tests on a Stag J-7028-Jupiter VI aircraft, reported in R. & M. 1399.[1] The work completes the general investigation of the range of unsupercharged engines initiated at the A. & A.E.E. in 1928.

The consumption of a Jupiter VIII F engine in a Wapiti aircraft was measured by means of a flowmeter in level flight at a series of ignition settings from 35 deg. to 51 deg. advance with a weak mixture obtained by opening the mixture control until the crankshaft speed fell 3 per cent. (termed the Weakest Mixture) at three heights, 2,000, 5,000 and 12,000ft. and at 2,000ft. with two other mixture strengths, one determined by a fall in crankshaft speed of 2 per cent. (termed the Intermediate Mixture), the other being that corresponding to a fall of 20 r.p.m. subsequently restored by opening the throttle and termed Normal Weak Mixture. Consumption loops at constant A.S.I. (and therefore constant engine torque and r.p.m.) were also determined over a range of mixture strengths.

The general conclusions are:—

(1) The effect of ignition timing on range with the Weakest Mixture is the same at all heights tested.

(2) Any variation in the effect of ignition timing with height and mixture strength is too small to be revealed by the tests.

(3) The range with the Weakest Mixture and at a fixed ignition setting between 35 deg. and 51 deg. advance is approximately independent of height.

(4) The gain in economy at 2,000ft. with any fixed ignition setting between 35 deg. and 51 deg. advance due to the use of the Intermediate and the Weakest Mixture instead of the Normal Weak Mixture is 5 and 10 per cent. respectively.

(5) No gain in economy is obtained by using a mixture weaker than the Weakest Mixture used during these tests.

(6) The total gain in range under most economical conditions of both ignition timing and mixture strength as compared with the Normal Weak conditions is about 17 per cent., but this figure implies an impracticably low cruising speed.

(7) The results agree qualitatively with R.A.E. bench tests with variable ignition, but the magnitude of the effect is greater in flight than in the bench tests.

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1 The range of aircraft at heights as affected by the use of altitude control. Flight tests on an aircraft with an air-cooled radial engine.—A. W. Nutt, Flt. Lt. A. F. Scroggs and E. Finn.

CINE-PHOTOGRAPHIC MEASUREMENTS OF SPEED AND ATTITUDE OF SOUTHAMPTON AIRCRAFT WHEN TAKING OFF AND ALIGHTING. By A. E. Woodward Nutt, B.A., and G. J. Richards, Ph.D., A.R.C.Sc., D.I.C. Communicated by the Director of Scientific Research, Air Ministry. R. & M., No. 1621. (13 pages and 8 diagrams.) September, 1934. Price 1s. net.

The accurate measurements of the take-off speed or alighting speed of a seaplane is a matter of some difficulty. The normal method used for type trial purposes is for an observer in the aircraft to read the speed indicated by the air speed indicator on a number of take-offs and alightings, the ordinary calibration and position error corrections being applied to the readings. This method is not accurate, however, for several reasons. In the first place, it is not easy for an observer in the aircraft to judge accurately the exact moment of leaving or touching the water. Secondly, the air speed is changing rapidly, making it difficult for the observer to read the A.S.I. accurately and also introducing errors due to lags in the A.S.I. system. Further, it is rarely possible on flight tests to measure the position error of the pitot-static head at a sufficiently high incidence, and extrapolation has to be made. Finally, the position error may be different in the proximity of the water from that found in free flight at an altitude.

For these reasons it was decided to investigate the possibility of taking cine-photographs of the take-offs and alightings of seaplanes, arranging for a time record to be made simultaneously on the film, and of measuring the speeds at take-off and alighting by an analysis of the records obtained.

At the same time it was thought that data on the lift of the aircraft might be obtained with a view to finding out whether abnormally high values of the lift coefficient occurred at take-off and on alighting, as had been found at Martlesham Heath for landplanes. [1], [2].

Accurate measurements of the take-off and alighting speeds of aircraft by this method is limited by wind gustiness and by the difficulty of determining accurately the wind speed at the time and place of test. The present experiments indicate a probable error of the take-off or alighting speed of approximately ± 1.4 knots. Improved methods of measuring wind speed may increase this accuracy for future tests.

The lift coefficients for the Southampton aircraft at the instant of take-off or alighting, over a wide range of incidence are considerably higher than those found for similar aircraft in free flight at an altitude. This increase appears to be the same on take-off and alighting, and irrespective of the directions of the runs in relation to that of the wind. In these respects the results are in general agreement with those found at the A. & A.E.E. for landplanes.

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1 D. Rolinson.—Take-off and landing of aircraft. R. & M.1406. (1931.)
2 D. Rolinson.—Measurements of take-off and landing runs. R. & M.1458. (1931.)

A STUDY OF THE FLOW IN THE BOUNDARY LAYER OF STREAMLINE BODIES. By H. M. Lyon, M.A., A.F.R.Ae.S. R. & M., No. 1622. (54 pages and 26 diagrams.) May 15, 1934. Price 3s. net.

In a previous report[1] a description was given of a series of experiments designed to show the effect of artificial turbulence in the wind tunnel stream on the comparative resistances of two models of airship hulls. Turbulence was produced by means of screens placed in the wind tunnel at various distances ahead of the model. Although in the bare tunnel, the drag coefficient of one model was about 50 per cent. higher than that of the other, with increasing turbulence the drag coefficients of both models increased and approached one another until they became approximately equal for the higher values of turbulence obtained. It was concluded that the higher drag coefficient of one model in the bare tunnel was due to an earlier transition from laminar to turbulent flow caused by a different pressure distribution, and that the increased drag due to turbulence was caused by a forward movement of the transition point on both models. There was, however, no indication that the drag coefficient would tend to an upper limit as the turbulence increased and the boundary layer became almost wholly turbulent. Some doubt was also expressed as to whether the type of flow in the boundary layer produced by artificial turbulence was the same as that produced by a forward movement of the transition point due to an increase of the Reynolds number.

In order to make a closer investigation of the type of flow in the boundary layer and of the reasons for the observed increase in drag under turbulent conditions it was proposed to measure the distribution of total head within the boundary layer at various positions on the model. As the models used in the earlier experiments were too small for this purpose, two larger ones were constructed, of the same shape, but double the scale.

Measurements of total head and surface pressure were made within the boundary layer of each of two models in the bare tunnel and at a distance of 2ft. behind a wire mesh screen. The distribution of skin friction has been calculated from the experimental results and also by a theoretical method and the integrated drag due to skin friction and that due to surface pressure have been compared with the measured drag.

The wide difference between the drag coefficients for the two models in the bare tunnel has been shown to be due to the effect of the pressure distribution on the position of the transition from laminar to turbulent flow within the experimental range of Reynolds number and may be expected to disappear at higher Reynolds numbers.

The transverse variation of mean velocity behind the screen caused a distortion of the curve of local distribution of velocity within the boundary layer, but had no appreciable effect on the total measured drag with the model 2ft. behind the screen. The increase in the measured drag behind the screen has been accounted for by the observed forward movement of the transition point.

A theoretical method has been developed for the calculation of skin friction and is capable of wider application when more experimental data is available.

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1 Lyon, R. & M., No. 1511

ON THE EFFECT OF DISCS ON THE AIR FORCES ON A ROTATING CYLINDER. By Alexander Thom, D.Sc., Ph.D. Communicated by Professor J. D. Cormack. R. & M., No. 1623. (10 pages and 14 diagrams.) January 5, 1934. Price 9d. net.

The rotors were built up from thin circular aluminium discs mounted on a steel spindle between short lengths of cylinder. Two sizes of discs were used, 3in. and 6in. diameter, and two sizes of cylinder 1in. and 2in. diameter. At the lower values of v^2V, k_L and K_D are almost identical with those obtained for the plain cylinder. At higher values of v^2V two interesting results are obtained:—the lift coefficient becomes very large and the drag becomes small and then rises suddenly.

TESTS ON MODELS OF ARMSTRONG WHITWORTH FOUR-ENGINED MONOPLANE. SUMMARY AND INTRODUCTION. By W. L. Cowley, A.R.C.Sc., D.I.C., R. Warden, Ph.D., M.Eng., and G. A. McMillan, M.Eng., of the Aerodynamics Dept. N.P.L. R. & M. No. 1624. (13 pages and 4 diagrams.) October 28, 1933. Price 9d. net.

Introduction and Reason for Inquiry.—The wind tunnel tests described in this report were upon models of a multi-engined monoplane designed by Messrs. Armstrong Whitworth Aircraft Company. The work is of special interest as the design is concerned with a type of aircraft rather than with a particular machine. In the design considered four air-cooled engines were mounted on the leading edge of the plane, two on each side of the body. The total all up weight was 25,000 lb.

Only the introduction and conclusions are given in the present report.

An analysis of the test results on the complete model and on the wings alone shows that the parasitic drag was about 340 lb. The added resistance due to the undercarriage was approximately from 4 to 6 per cent. of the drag of the complete model.

The mutual interference between the body and wings appears to be different in the two models tested. In the first model it varied from 21 lb. to 60 lb. between full scale lifts of 10,000 and 18,000 lb., whereas in the second model the corresponding figures were 44 lb. to 89 lb. or an increase of 23 lb. to 39 lb. over the first model.

An examination of the top speed conditions of the aircraft suggests that, when allowance is made for scale effect according to a power law, the drag of the complete model is only about 4.5 per cent. too high for a top speed of 175 m.p.h.

The effect of slipstream on the performance of the aircraft is uncertain.

TESTS OF SIX AEROFOIL SECTIONS AT VARIOUS REYNOLDS NUMBERS IN THE COMPRESSED AIR TUNNEL. E. F. Relf, A.R.C.Sc., R. Jones, M.A., D.Sc., and A. H. Bell, of the Aerodynamics Department, N.P.L. R. & M., No. 1627. (28 pages and 6 diagrams.) September 22, 1934. Price 1s. 6d. net.

The present report gives aerodynamic data on six aerofoil sections, *viz.*, R.A.F.28. R.A.F.38, R.A.F.48, R.A.F.34, Clark YH and Göttingen 387, which have been tested in the Compressed Air Tunnel over a wide range of Reynolds numbers. The aerofoils were of 6.1 aspect ratio with square tips, the span being 48in. and chord 8in. Corrections for the drag and interference of the supports, for the deflection of the aerofoils under load, and for the constraint of the tunnel jet, have been applied, so that, apart from possible effects of tunnel turbulence, the results as given apply directly to free air conditions at the Reynolds numbers stated.

The question of turbulence effects is still under investigation by comparison with full scale flight tests, and the evidence at present available is not sufficient to enable a final conclusion embracing all types of wing section to be reached.

DIRECT CALIBRATION OF COMPENSATED HOT-WIRE RECORDING ANEMOMETER. By C. Salter, M.A., and W. G. Raymer, of the Aerodynamics Department, N.P.L. R. & M., No. 1628. (9 pages and 7 diagrams.) March 3, 1934. Price 9d. net.

When a very fine platinum wire is used in conjunction with a valve amplifier and oscillograph to record rapid local changes in wind speed it is normally not practicable to calibrate the apparatus directly and the scales of the records must be calculated from experimental constants.

It is usual also to adjust the frequency-amplification curve of the amplifier to compensate both in regard to amplitude and phase for the thermal lag of the wire at high frequencies, and where necessary for a similar effect in the oscillograph.

It has been considered desirable to check the arrangement by direct calibration, and this has been done by oscillating the wire in a direction parallel to that of the stream, thus inducing a variation in the velocity of the wind relative to the wire.

The results show that the apparatus has been slightly over-compensated with respect to the magnitude of the variations and that the compensation for phase lag is inadequate, but that there is no fundamental error in calculating the scales of the records.

THE NORMAL ACCELERATION EXPERIENCED BY AEROPLANES FLYING THROUGH VERTICAL AIR CURRENTS. PART II. THE INTERPRETATION OF ACCELEROMETER RECORDS. By H. R. Fisher, B.A. Communicated by the Director of Scientific Research, Air Ministry. R. & M., No. 1629. (16 pages and 25 diagrams.) January 1, 1934. Price 1s. net.

This report develops the material of Part I (R. & M.1463)* in so far as it may be applied to the deduction of information on the structure of atmospheric turbulence from records of normal acceleration.

In records taken mostly in cumulus clouds several traces were found to be attributed to well-defined local and extended vertical currents reaching their maxima in from 50 to 100ft. and usually accompanied by small boundary eddies, while independent horizontal eddies of from 100 to 200ft. diameter also appear to be frequent; but these conclusions should be accepted with reserve until other meteorological information and better aerodynamic calculations become available.

Since lateral motions and variations in forward speed are liable to produce on the average a positive (upward) acceleration, measurements for comparison of gusts should be made from a mean acceleration if this is positive. The preponderance of positive peaks over negative peaks noted in R. & M.1441[1] is thereby reduced, but appears to persist in the case of the highest peaks, indicating sharper up-gusts than down-gusts.

To obtain information on the structure of gusts it is best to use as small an aircraft as possible. The most direct and satisfactory measurement of gust loads in any particular case is by means of wing deflection; if a single accelerometer is used, it should be supplemented by a record of bank. The gust loads on a large aircraft can conveniently be estimated from tests on one about half its size.

Appendix II sketches a rough method of comparing the limitations imposed by lift-curve characteristics and strength on the capabilities of different aeroplanes as gust-measuring machines.

* The normal acceleration experienced by aeroplane flying through vertical air currents—Part I.—H. R. Fisher.

(1) Investigation of atmospheric turbulence by aircraft carrying accelerometers. By W. G. Jennings and R. P. Alston, October, 1931.

AN APPLICATION OF MATRICES TO OSCILLATION PROBLEMS. By W. J. Duncan, D.Sc., A.M.I.Mech.E., and A. R. Collar, B.A., B.Sc. R. & M. No. 1630. (5 pages.) Price 4d. net.

The present report gives a summary of two papers. The first of these, "A Method for the Solution of Oscillation Problems by Matrices," was published in the *Phil. Mag.* for May, 1934. The second, entitled "Matrices Applied to the Motions of Damped Systems," was published in the *Phil. Mag.*

The object of the investigation was the development of arithmetical methods for the solution of problems on the small oscillations of dynamical systems with special reference to the cases where the number of degrees of freedom is large.

In the first of the papers summarised the application of the method is restricted to systems where damping forces are absent, but this restriction is removed in the second paper.

The method of solution by matrices has distinct advantages of ease and rapidity, more especially when interest is confined either to the fundamental or to the most rapid oscillation, and when the number of degrees of freedom is large.

MEASUREMENTS OF FORCES AND MOMENTS ON A "PUSS MOTH" MODEL. PART I: WITH SCHRENK FLAPS FITTED TO MODEL. PART II: WITH MODEL YAWED. A. S. Batson, B.Sc. R. & M. No. 1631. (5 pages and 17 diagrams.) February, 1934. Price 6d. net.

In an endeavour to increase the gliding angle of a machine, experiments were carried out on a "Schrenk" type of flap. This consisted of a flap of moderately small chord fitted to the under surface of the wing towards its trailing edge. It had been found that a flap fitted this way increased the lift as well as the drag of the wing and in these experiments preference was given to this type as it was desired to find out what alteration to gliding angle could be obtained with a flap of moderately small chord.

Measurements of lift, drag and pitching moments were made over a range of incidence 0 deg. to 20 deg. approx. on a tenth scale "Puss Moth" model fitted with two different arrangements of flap. The effect of flap on aileron control was also tried. It was possible to obtain an increase in gliding angle from these experiments of nearly three degrees, from 5.5 deg. to 8.4 deg. This was obtained by means of flaps, the length of which approximated to the span. They thus shielded the ailerons, the control of which was reduced throughout the range of incidence.

Longitudinal and lateral forces, rolling, pitching and yawing moments were obtained over a range of incidence extended to a little beyond the stall. The angle of yaw varied from 0 deg. to 20 deg. In general, the results do not differ greatly from those for models of other aeroplanes.

ON THE CALCULATION OF STEADY FLOW IN THE BOUNDARY LAYER NEAR THE SURFACE OF A CYLINDER IN A STREAM. By L. Howarth, B.A., B.Sc., Busk Student. Communicated by Dr. S. Goldstein. R. & M. No. 1632. (56 pages and 9 diagrams.) July 17, 1934. Price 2s. 6d. net.

This paper has been written with a view to comparing the various methods so far suggested of boundary layer analysis for steady two-dimensional flow past an obstacle. Some of the methods, as given by their authors, can be reduced to more convenient forms for the solution of any given problem. This has been done where possible and conclusions drawn as to the usefulness of each method.

THE REDUCTION OF DRAUGHTINESS OF OPEN COCKPITS. By B. Lockspeiser, M.A., and A. Graham, M.Sc., D.I.C. Communicated by the Director of Scientific Research, Air Ministry. R. & M. No. 1633. (12 pages and 16 diagrams.) July 13, 1934. Price 1s. 6d. net.

Most open cockpits are draughty and cold to sit in and hitherto little has been done (except in the matter of clothing) to increase the comfort of the pilot. One notable exception should be mentioned—the type of cockpit where the pilot sits in a stream of air warmed by passing through the radiator and entering the cockpit through an opening in the floor. This layout, made possible by the position of the radiator, provides a comfortable cockpit by simultaneously increasing the draught and making the draught a pleasant one. But with most existing types of aircraft this is not possible and any improvement in the pilot's comfort is to be looked for in the reduction of draughtiness.

Range of Investigation.—Qualitative and quantitative measurements of draughts in a full-scale model of a Moth cockpit and around the opening have been made in the 5 ft. wind tunnel. The nature of the airflow, using small models, has also been studied in the smoke tunnel. Cockpit heating measurements, have been made relative to draughtiness. Both the standard type and the divided type windscreen, with horizontal slit, have been used in these experiments and the effect of semi-enclosing the cockpit with a collapsible hood has been investigated.

The divided windscreen is to be preferred to the standard type from the point of view of draughtiness but the greatest reduction of draughtiness was obtained by the use of a hood semi-enclosing the opening. Such a hood can be made collapsible or movable at the will of the pilot and it need not appreciably impair his field of view or prevent him from looking round the side.

TESTS OF RECTANGULAR AND TAPERED AEROFOILS BASED UPON THE R.A.F. 34 SECTION. By W. L. Cowley, A.R.C.Sc., D.I.C., and R. Warden, Ph.D., M.Eng., of the Aerodynamics Department, N.P.L. R. & M. No. 1635. (23 pages and 11 diagrams.) August 11, 1934. Price 1s. 3d. net.

In connection with the design of a cantilever monoplane, tests were carried out on a series of aerofoils whose ordinates measured from the chord line were multiples of those of R.A.F.34, this section being chosen owing to its small centre of pressure travel, and consequent reduction of torsion of the wing. The thickness ratios tested were 5, 10, 15, 20 and 25 per cent. in addition to the basic R.A.F.34 of 12.6 per cent. Scale effect was investigated by testing at 60, 75, 90 and 100 ft./sec. Finally three tapered wings were tested—two with a straight taper, which differed only in the shape of the wing tip, the third being approximately elliptical in plan.

Increasing the T/C (thickness/chord) ratio up to 15 per cent. results in increase in maximum lift, but there is no appreciable change on further thickening. Scale effect increases the maximum lift on the thin sections but decreases it on the thick ones. The profile drag is very nearly constant up to a K. of 0.4; there is little change on increasing the T/C ratio up to 15 per cent., while the two thicker sections have practically the same value though higher than the thin sections. The centre of pressure does not change much with variation in T/C ratio except at low lifts in the thinner sections it is farther back.

The conclusion is that there is very little difference between the three wings tested, but the straight tapered, rounded end is the best.

AN APPROXIMATE METHOD OF DETERMINING THE AERODYNAMIC LOADING ON THE WINGS OF A MONOPLANE. By A. G. Pugsley, M.Sc. Communicated by the Director of Scientific Research, Air Ministry. R. & M. No. 1643. (8 pages and 9 diagrams.) July 18, 1934. Price 6d. net.

The aerodynamic loading on the wings of a monoplane is usually estimated either by the Fourier series method of analysis or by a simple strip theory.

The new method, which depends essentially upon the correction of strip theory results for lift and rolling moment by appropriate "induction factors," is described in relation to the determination of lift, rolling moment, lift distribution, pitching moment and drag. Values for the necessary induction factors are given and the lift distributions obtained by the new method for a number of examples are compared with those derived by the series method. Some points affecting the practical application of the new method are noted.

It is found that in ordinary circumstances the new method gives results approximating to those given by the series method and yet is almost as simple to use as strip theory.